National Aeronautics and
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Jet Propulsion Laboratory
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Pasadena, California

Atmospheric Infrared Sounder

Changes To AIRS Spectral Calibration For V6: A Progress Report

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Purpose

- Describe progress on algorithm development for an improved AIRS spectral calibration
  - *New method for determining instantaneous frequency shifts*
- Mention algorithms developed to clean up AIRS spectra prior to resampling to a fixed frequency set
  - *Removal of outliers*
  - *Filling small spectral coverage gaps*

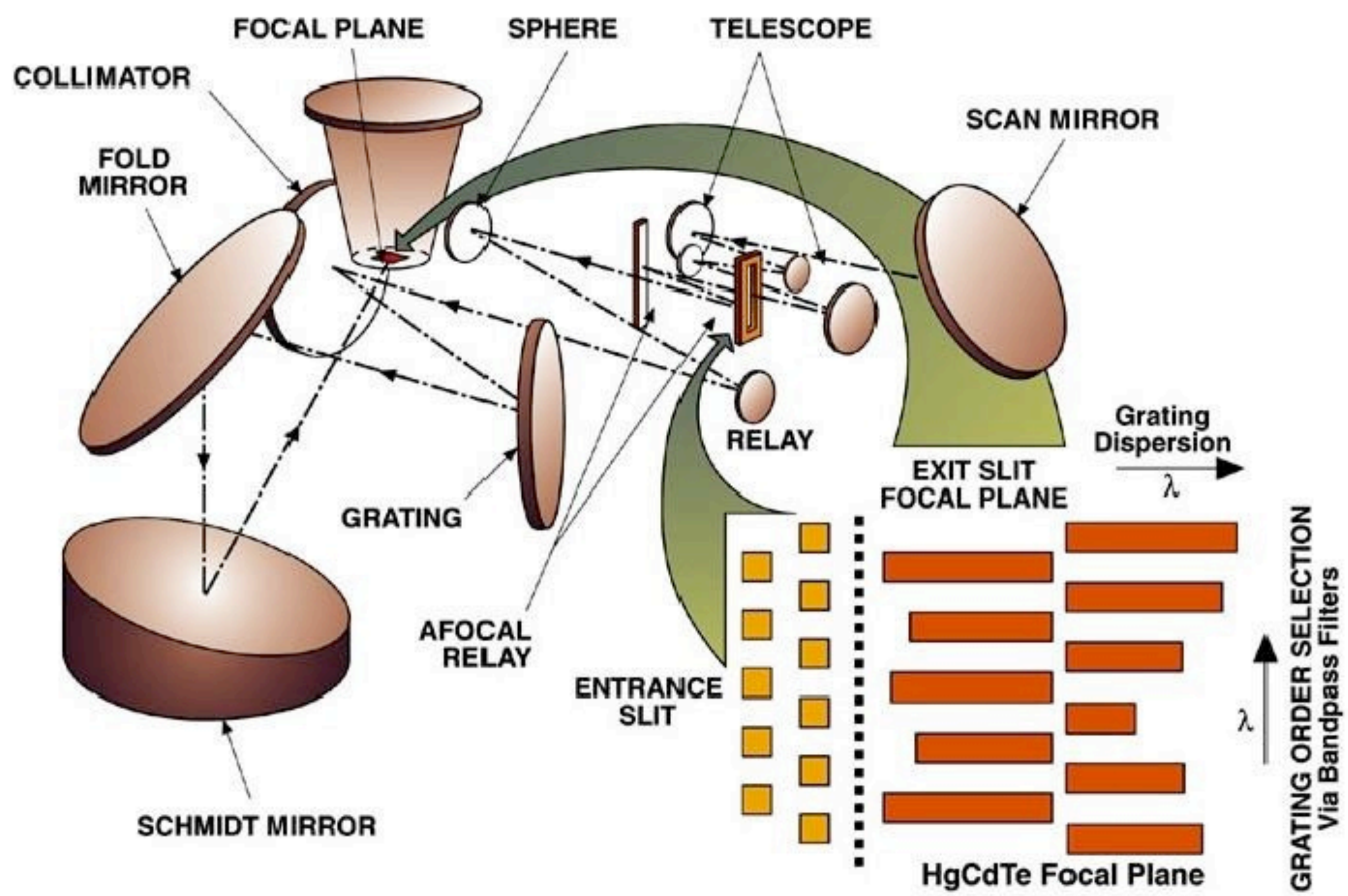
Acknowledgements

- **This talk summarizes a lot of work by several different people**
  - ***Larrabee Strow and Scott Hannon***
    - (Obs – calc) studies used to determine the spectral shifts
    - Training data sets and expanded channel set used in spectral “cleaning” and gap filling
    - Frequency shift determination algorithms
  - ***George Aumann***
    - Overall guidance of the effort at JPL
  - ***Yibo Jiang***
    - software prototyping at JPL

Outline

- **Frequency shift determination**
  - ***Old algorithms***
  - ***New algorithm***
- **Spectral "cleaning"**
  - ***I have included slides on the clean-up algorithm for completeness, but I do not have time to go over them in detail***
  - ***Refer to my SPIE talk from last August (conference #7091)***
- **Gap filling**
- **Output product plans**
- **Summary**

AIRS Optics and Focal Plane



- Spectral filters at each entrance slit and over each FPA array isolate color band (grating order) of interest

V5 (Old) Frequency Shift Algorithms (1 of 2)

- **Focal plane detector assembly models specify relative detector positions at three different temperature set points (149K, 155K, 161K)**

- **A spectrometer grating model specifies the relation between detector SRF centroids and detector physical positions (relative to the grating and the imaging optics)**

V5 (Old) Frequency Shift Algorithms (2 of 2)

- **Two algorithms dynamically determine the shift by fitting flight data to the models**
  - ***Use near-nadir clear spectra, averaged over a granule, and a set of narrow atmospheric lines of known frequency***
  - ***Use observations of the on-board spectral calibrator (parylene sheet), also averaged over a granule***

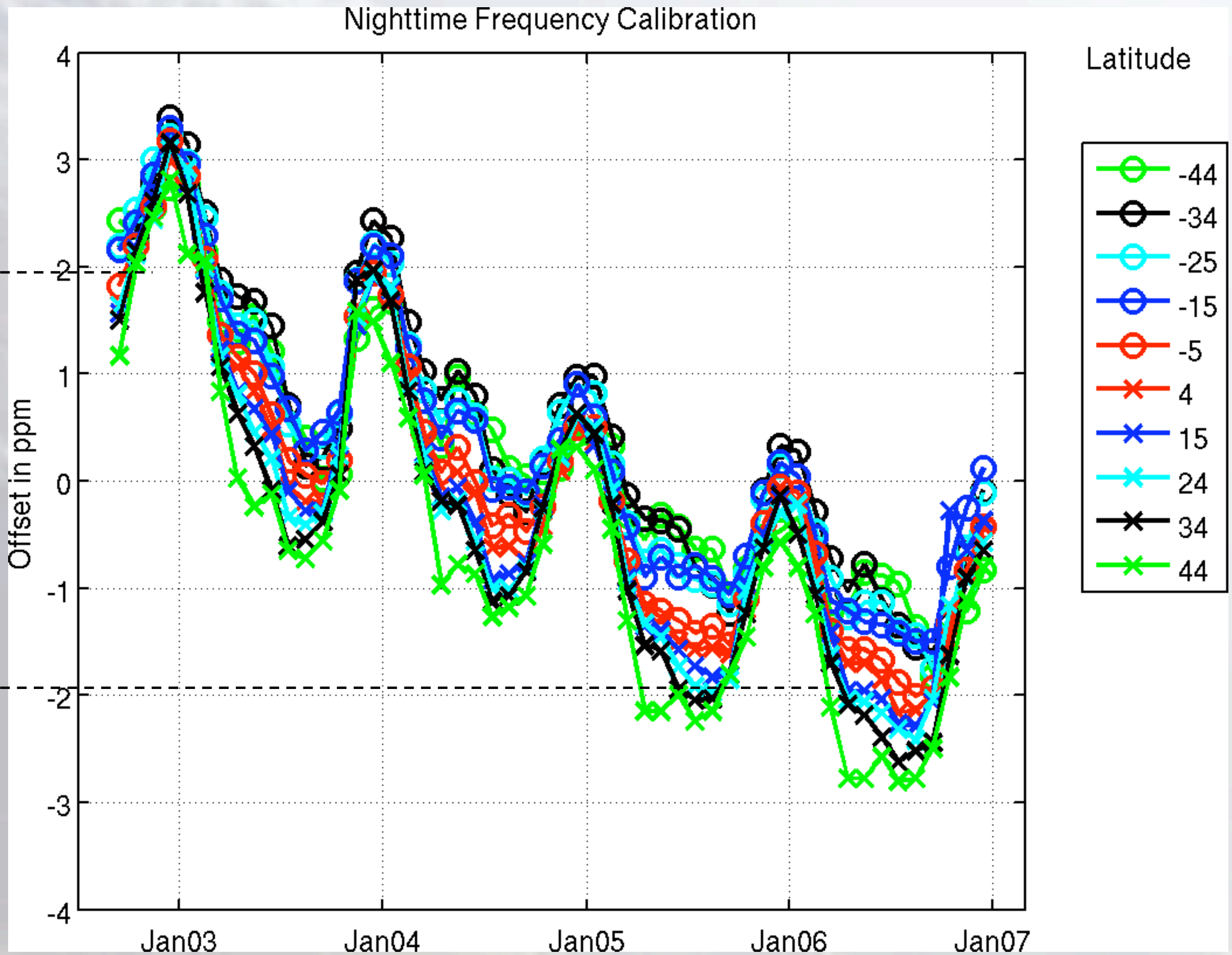
- **Results from both techniques are written to the output L1B file, but V5 L2 makes no use of either**
  - ***The shifts are well within AIRS specs and do not affect weather forecasting or most other uses of AIRS data***
  - ***The algorithms, though pretty good on average, produce noisy results***

V6 (new) Frequency Shift Algorithm Overview (1 of 2)

- **Frequencies shift on 3 time scales**
  - ***Orbital***
    - Temperature related, but details are not understood
    - Not well correlated with any single instrument temperature or with the choke point heater current
  - ***Seasonal***
    - Temperature related
    - Correlated with solar beta angle
  - ***Secular (long-term non-periodic) drift varying approximately like a decaying exponential with time***
    - Cause unknown

AIRS Frequency Shifts

< 1 ppmf/yr



V6 (new) Frequency Shift Algorithm Overview (2 of 2)

- **The algorithm as it stands today at JPL will determine the frequency shift using a table entered with three parameters**
  - ***Orbital phase***
  - ***Month***
  - ***Year***
- **The values in the table are based on the results of work by Scott Hannon who determined actual AIRS frequency shifts throughout the mission from an (obs – calc) analysis**

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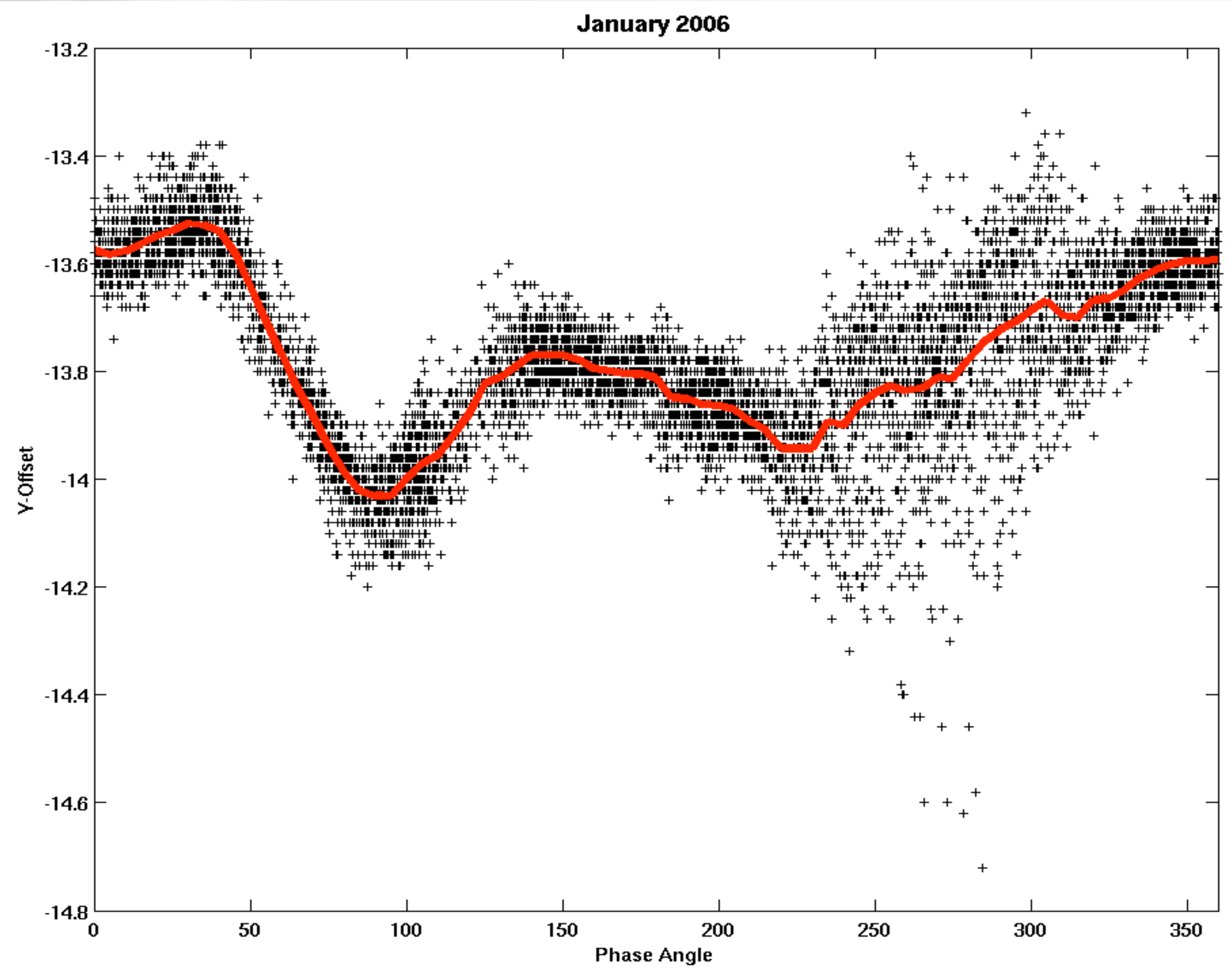
Measured Shifts from Hannon One Month (January 2006)

- Hannon determined AIRS frequency shifts on a per granule basis for the entire mission through at least June 2008
- The sample at right shows the shifts for January 2006 as a function of orbital phase
- One plotted point per granule



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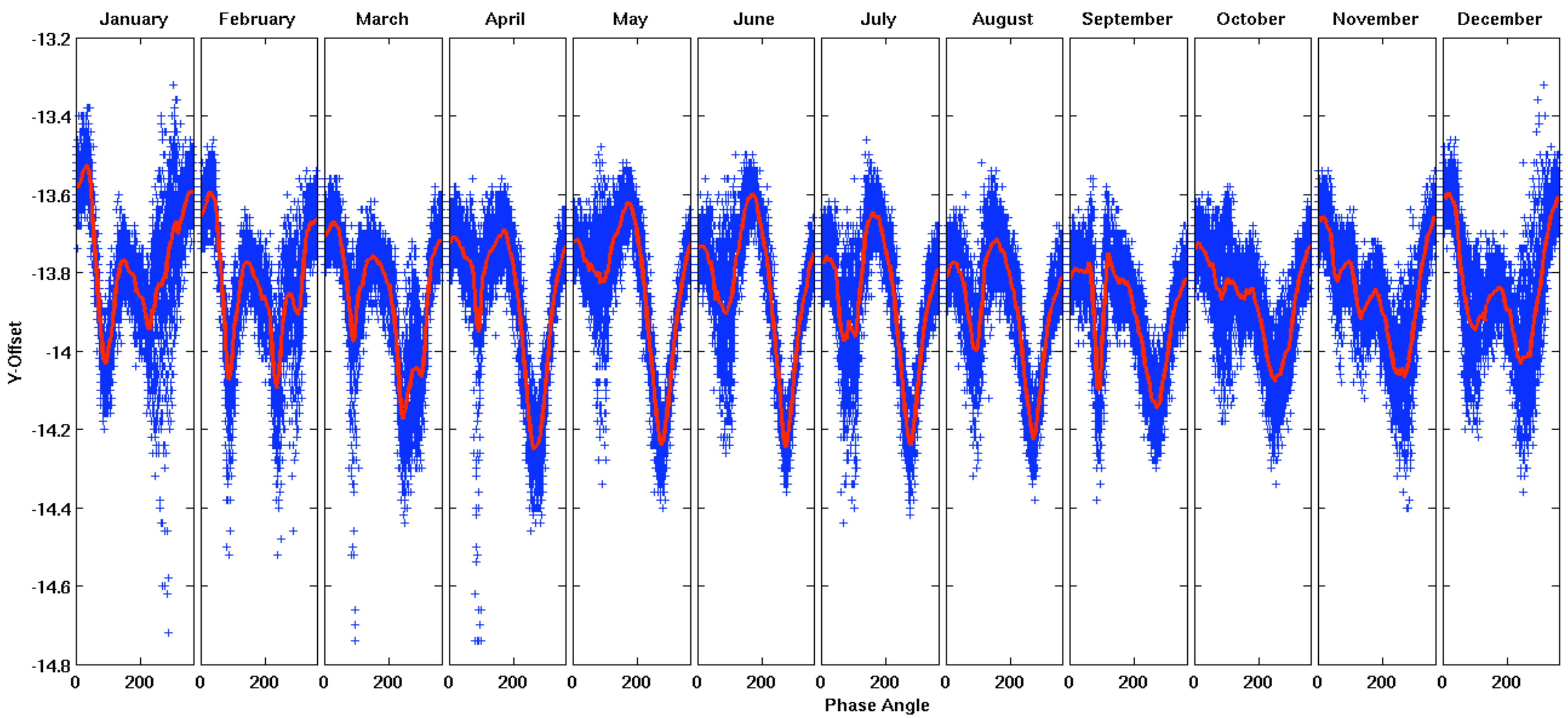
Measured Shifts from Hannon Year 2006



- **The plot above shows the averages in 5° bins for all 12 months of 2006 plotted next to each other**

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Secular Variation—Mission Overview

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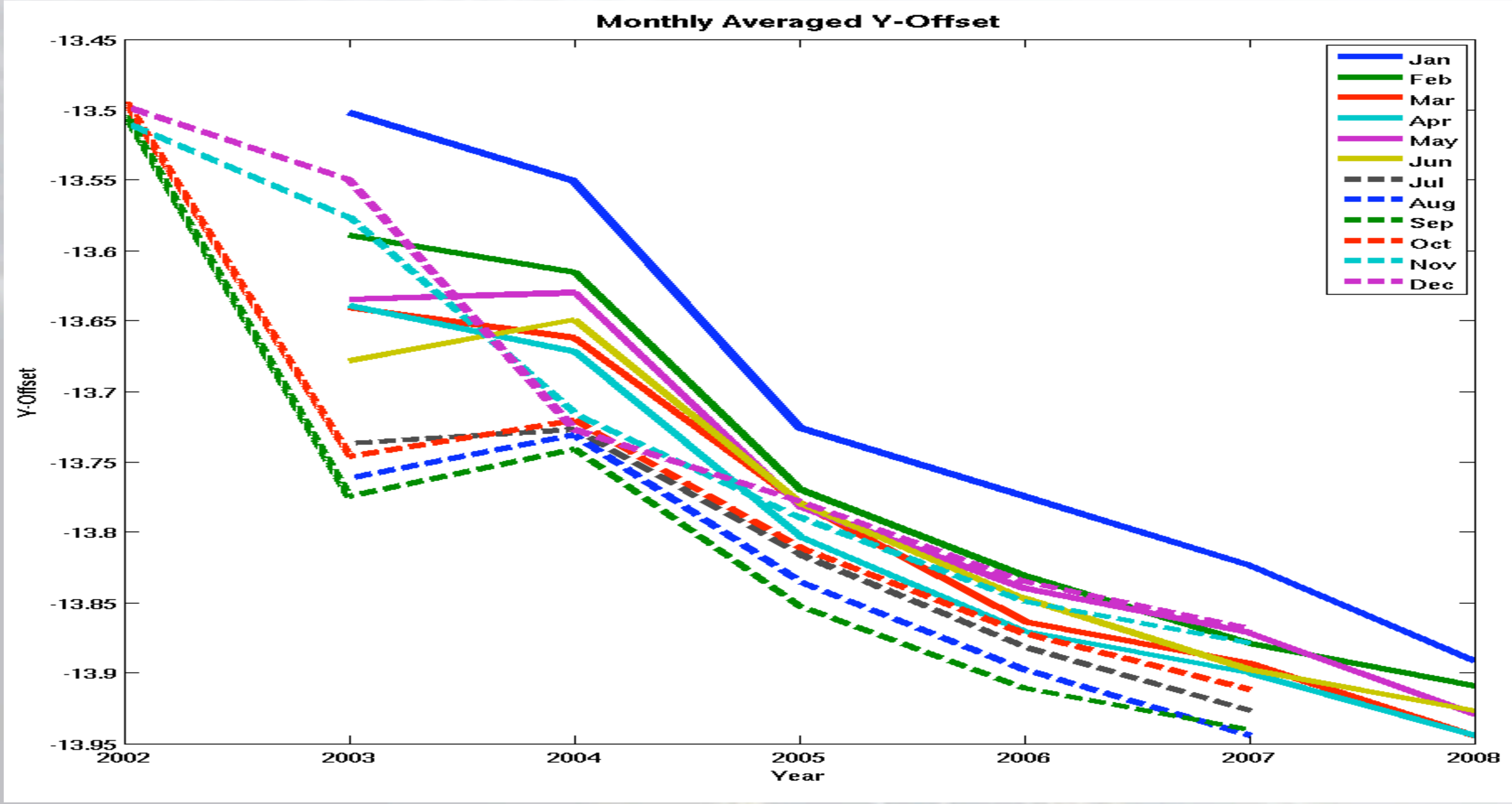
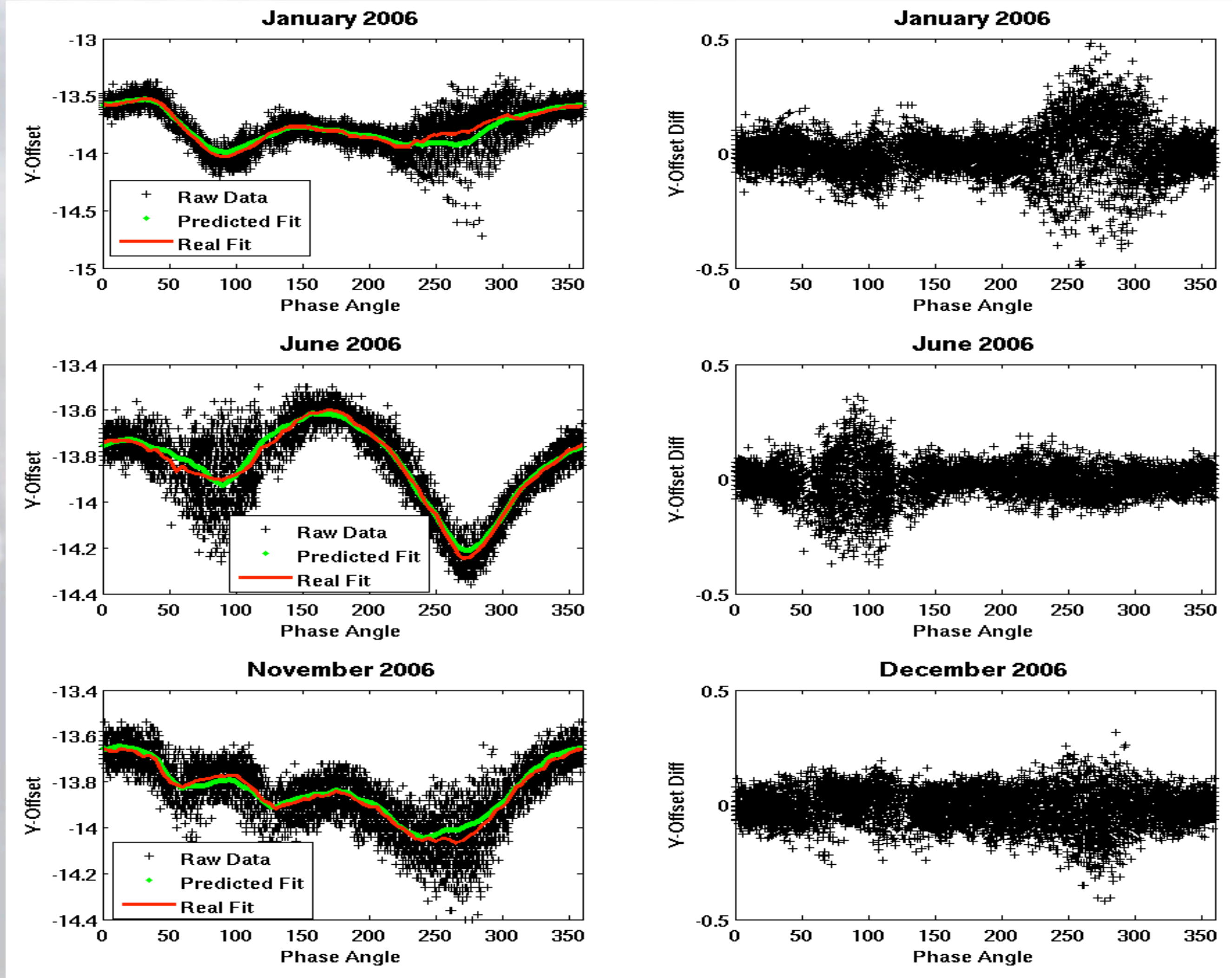


- The year-to-year trend for each month is shown

Prediction Results

- **0.1 micron corresponds to a worst case error (on the steep slope of a CO_2 line) of 12 mK**



Planned Improvements

- The present approach combines seasonal and secular effects into a table with a time resolution of one month—possibly too coarse

- Strow and Hannon are working on a closed expression which will calculate the shift in microns as a function of time. It will handle all three time scales simultaneously and eliminate the use of the table.

Spectral "Cleaning" (1 of 2)

- **In every spectrum, dead or noisy channels have their radiances replaced by radiances of other AIRS channels which tend to be correlated with them**
  - ***Correlated channels are***
    - Both window channels or
    - On the same spectral line or
    - On two lines of the same species with nearly the same strength
  - ***Every channel has had a list of possible replacement channels prepared***
  - ***58 of the 2378 channels have been dead since launch and are always replaced***
  - ***A few other channels have time-dependent or scene-dependent noise and are occasionally replaced***

Spectral “Cleaning” (2 of 2)

- **Only noisy channels are replaced**
  - ***Almost all channels in each spectrum are simply copied over from the Level 1B product***
  - ***The “cleaning” algorithm involves no resampling, interpolating, or extrapolating***
- **Determining and replacing noisy channels is a two-pass process**
  - ***Pass 1***
    - For each granule (six minutes of data) calculate NEΔT. If a channel’s granule-average NEΔT exceeds 2K its radiance is replaced
  - ***Pass 2***
    - Using principal component analysis, calculate difference between Pass 1 result and a reconstructed spectrum. Mark and replace any channel whose difference exceeds 5K

Gap Filling

- **Scott Hannon provided a superset of AIRS channels (2834 total) which fill in the small gaps between some detector modules (not the large gap)**
- **Hannon provided 245 spectra containing all the channels for use in training**
- **For each synthetic channel, a set of correlated real AIRS channels was determined**
- **Gaps are then filled by pretending that the synthetic channels are outliers and using the "cleaning" algorithm**

Output Product Plans

- **Level 1B will contain the instantaneous frequency for each channel**
  - ***We may or may not keep the results of the old V5 algorithms as well***
- **At present, we do not intend to produce a Level 1C product (cleaned, gap-filled, and resampled) for every granule**
  - ***We could provide three routines that would separately clean, gap fill, and resample***
  - ***Users can create their own Level 1C products or***
  - ***The GES DISC can produce L1C on demand***

Summary Of V6 Spectral Cal Changes (1 of 2)

- **L1B**
  - ***L1B radiances remain the primary L1 product and are not affected by changes in spectral calibration***
  - ***New algorithm for determining instantaneous frequency shifts is based on past history of shifts determined by Hannon at UMBC***
    - This algorithm is accurate to better than 0.15 micron
    - The details of the algorithm are being revised to replace the table with a formula
  - ***All the old and new algorithms output one instantaneous frequency per granule for each channel***

Summary Of V6 Spectral Cal Changes (2 of 2)

- **L1C**
  - ***New products—cleaned, gap-filled, and resampled radiances***
    - The cleaning and gap filling algorithms are well developed but need validation
    - We recommend providing routines for users to generate their own cleaned, filled, and resampled L1C products as needed
- **L2**
  - ***TBD***

Backup

Rationale For This Work (1 of 2)

- **Ideal spectrum**
  - ***Each channel represents a truly independent measurement (no spectral cross-talk)***
  - ***No gaps or overlaps in spectral coverage***
  - ***Noise is purely Gaussian***
  - ***Channel frequencies fixed in time***
- **Since it is a grating spectrometer, AIRS excels at point #1 above**
- **AIRS Level 1B spectra differ from this ideal in the following ways**
  - ***Small spectral coverage gaps and small overlap regions exist between AIRS detector arrays (focal plane design constraints)***
  - ***A small number of AIRS channels have non-Gaussian noise (IR detectors in some bands pushed the state of the art at the time)***
  - ***Very small frequency shifts with time exist (small, variable temperature gradients exist within the spectrometer in spite of the fact that its temperature is tightly controlled)***

Rationale For This Work (2 of 2)

- **We want to eliminate the features of Level 1B which complicate climate studies**
  - ***Instantaneous channel frequencies will be measured***
  - ***Channels exhibiting excess non-Gaussian noise will be replaced (spectra "cleaned")***
  - ***Frequency coverage gaps and overlaps will be removed ("gap filling")***
  - ***Radiances (optionally) resampled to a fixed frequency set***
- **Level 1B radiances will remain the primary Level 1 AIRS product—"cleaned", "gap filled", and resampled radiances will be called Level 1C**

- **Examples**

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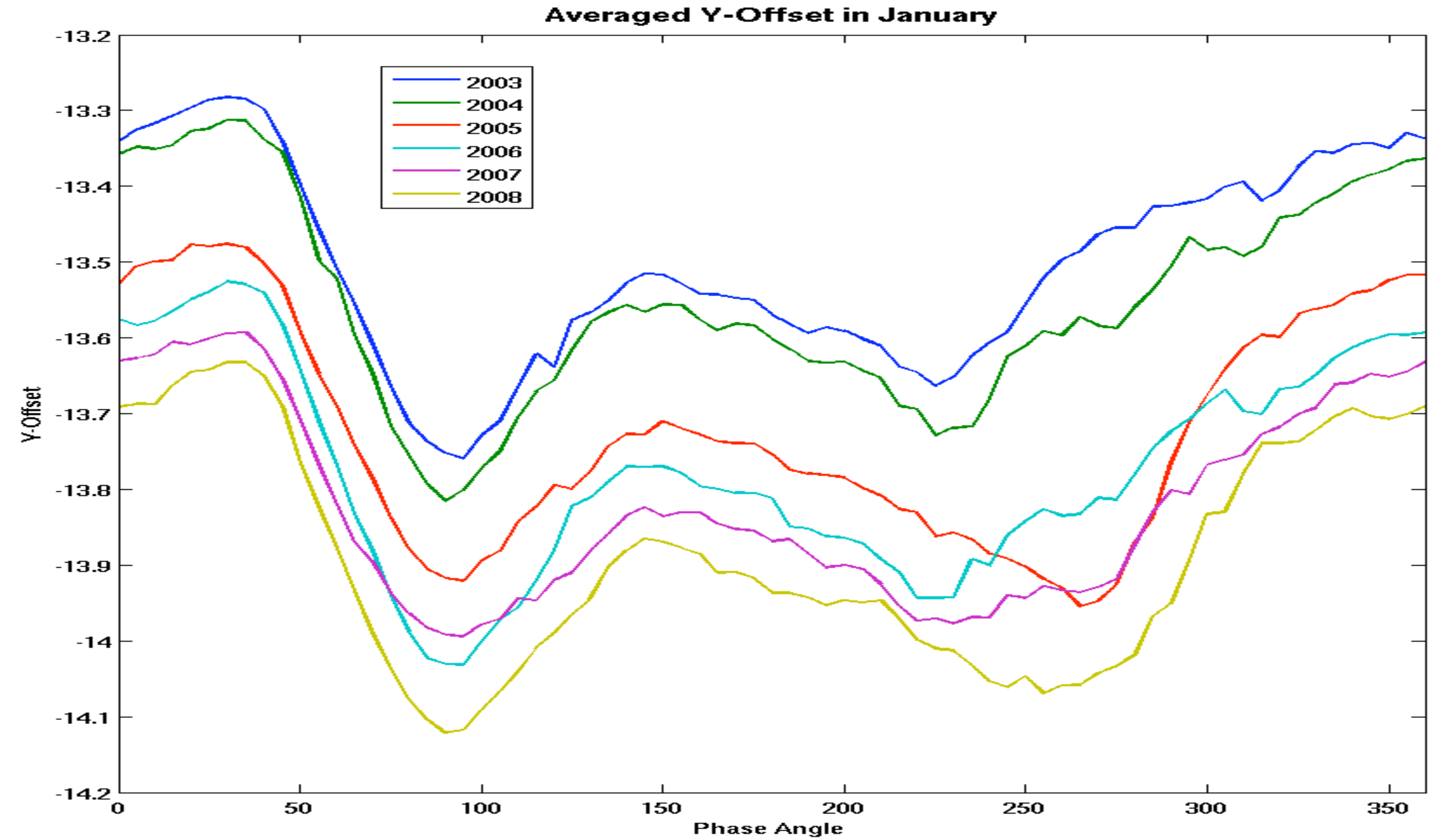
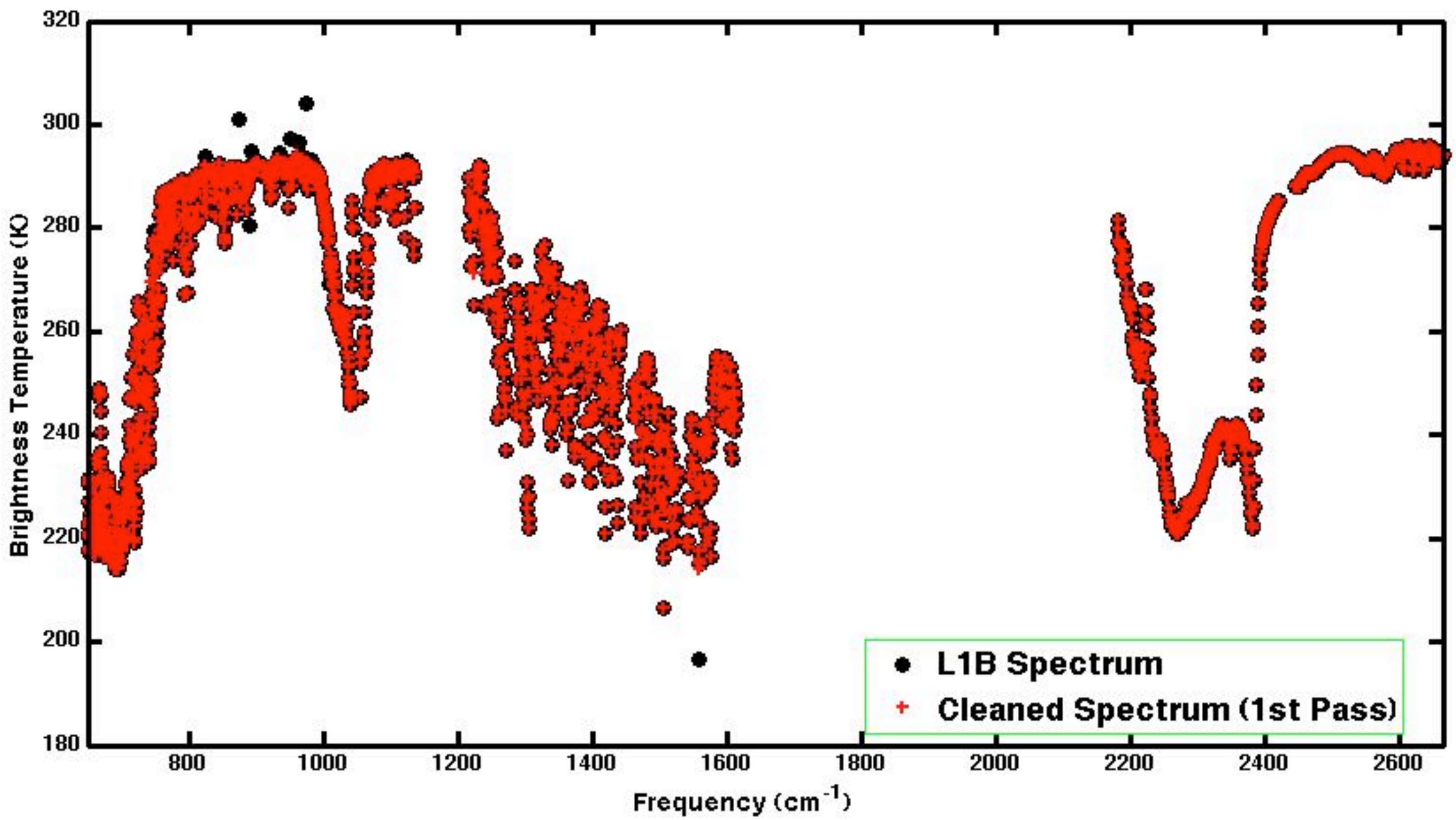
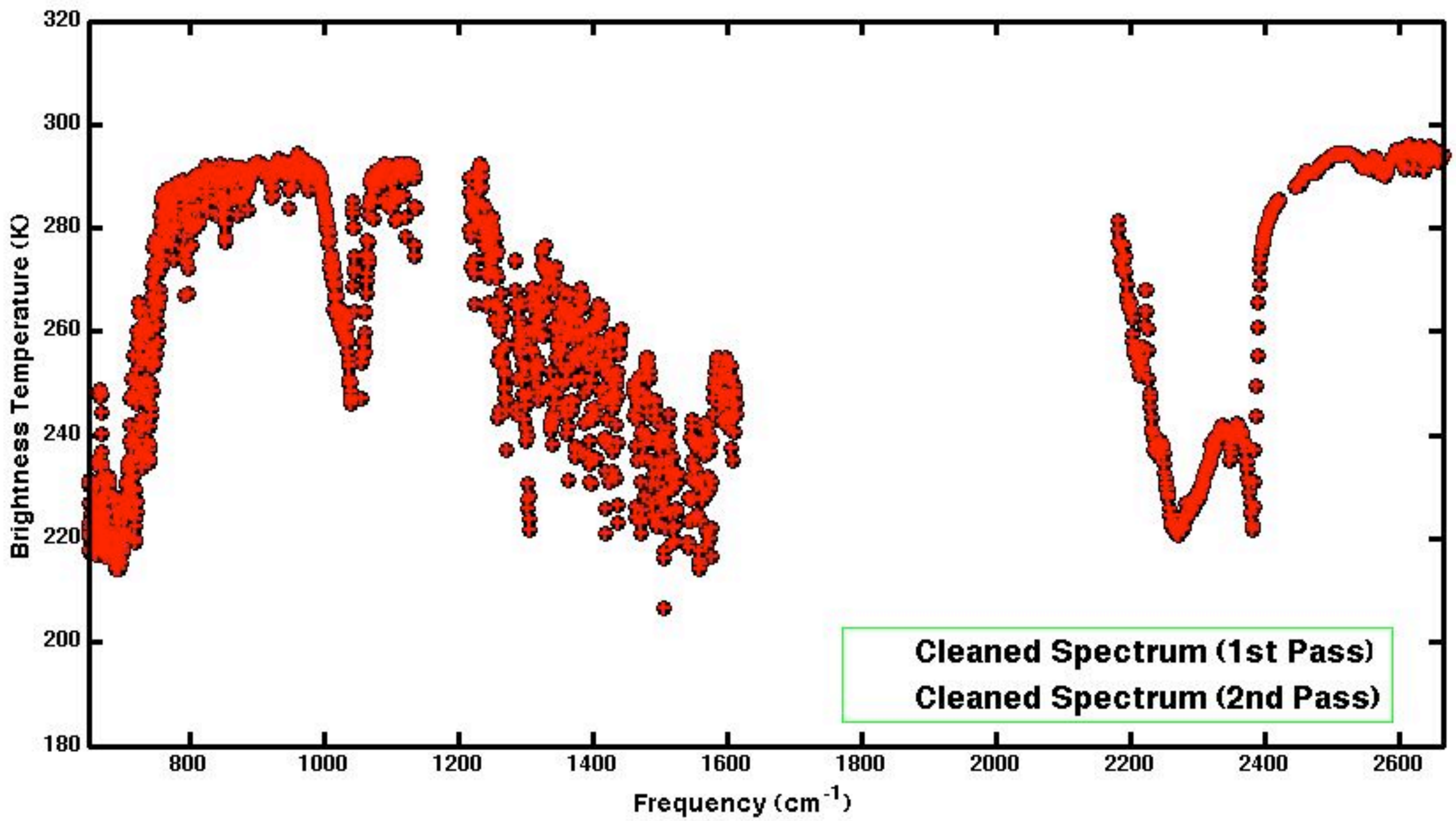
Year-to-Year Trends—January



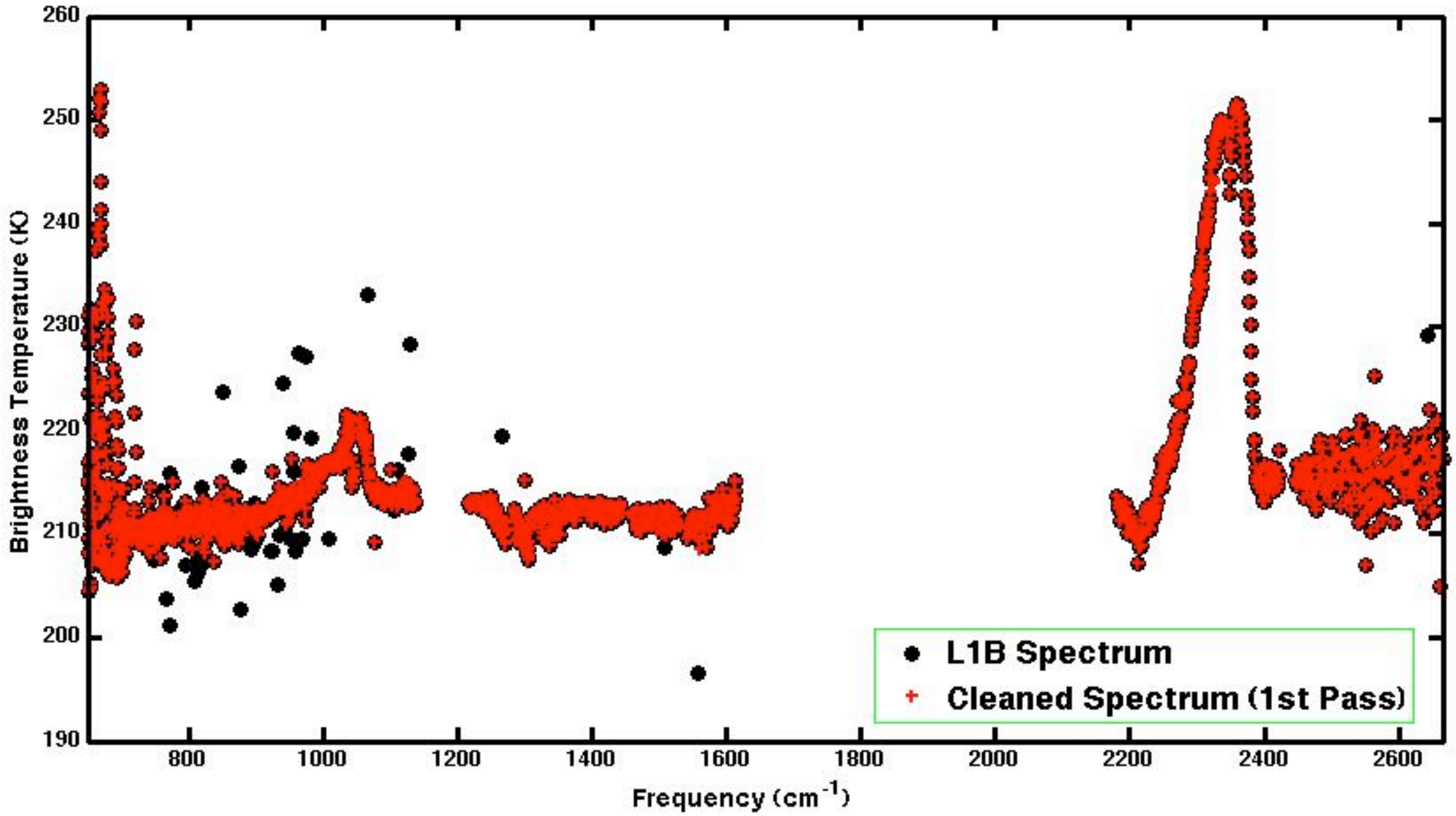
Sample AIRS Spectrum—First Pass



Sample AIRS Spectrum—Second Pass



Cold Scene Spectrum—First Pass



Cold Scene Spectrum—Second Pass